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Dynamic Link from Liftoff to Final Orbital Insertion for a MEO Space Vehicle

Jack K. Kreng and Gleason Q. Chen

Abstract

During the entire launch sequences from liftoff to final orbital insertion of a space vehicle (SV), adequate link requirements are to be maintained for telemetry, tracking, and command (TT&C) for uplink and downlink services, from launch vehicle (LV) and SV to ground stations (GS). A successful space vehicle launch required adequate link coverage with good radio frequency (RF) performance. The chapter is an extension of the IEEE/Aerospace Conference 2019 paper entitled Dynamic Link Analysis and Application for a MEO Space Vehicle published by the authors. The emphasis in this chapter is on the addition of the three distinctively different tracking waveforms and their associated links, used from liftoff to final orbital insertion. This chapter will describe the three required dynamic link analyses (DLA) to cover (a) the LV link from liftoff to its end of line of sight (LOS), (b) the LV link from LOS to Tracking and Data Relay Satellite System (TDRSS) at beyond line of sight (BLOS), and (c) the final tracking link using Space-to-Ground Link Subsystem (SGLS) or non-SGLS (NSGLS) link for the earliest or best separation time of the SV from the LV. The chapter discusses the concept of the dynamic link analysis, SV antenna switching schedule, recommended SV separation time, as well as the performance for different launch scenarios within the 24-h launch window. Topics include antenna patterns, launch trajectories, elevation angle and clock and cone angle geometry, and dynamic link budget.

Keywords: wide band communications, satellite tracking

1. Introduction

Recently, there was an interest to extend the present dynamic link analyses (DLA) beyond the early launch period to cover the period after the space vehicle (SV) separation from launch vehicle (LV), which includes both booster and second stage engine. The dynamic link from liftoff to final orbital insertion considers both geometric (visibility coverage) and radiometric (link margins for all downlink and uplink services) adequacy in the three launch stages. The purpose of the dynamic link study for the launch is to provide the earliest and accurate time for final SV separation and orbital insertion as compared to previous method which only relied on visibility tracking coverage to the end of line of sight (LOS).

The present DLA typically covers only two stages of LV tracking, including (a) liftoff to the end of LOS link and (b) the end of LOS to a period before SV

payload (PL) separation from LV, using LV, to Tracking and Data Relay Satellite System (TDRSS) [7] satellite link, which is also called beyond line of sight (BLOS) link. A third SV tracking, after SV payload separation from LV, is a tracking link between SV and a ground station (GS). This third SV tracking is now added in this chapter.

The tracking link used from liftoff to the end of LOS uses a UHF noncoherent FSK signal for command and a digital FM or BPSK for tracking telemetry link as described in detail in [2]. From the end of LOS to BLOS, the tracking telemetry link is usually a BPSK or QPSK signal, using a NASA Tracking Data Relay Satellite System to relay tracking data from the LV to White Sands or Goddard ground station (WSGT/GRGT) and finally routing it to other user ground stations. After SV payload separation and orbital insertion, the SV tracking link to an Air Force Satellite Control Network (AFSCN) ground station [3] will use Space-to-Ground Link Subsystem (SGLS) or a non-SGLS (NSGLS) waveform described in [3, 4] and in Section 3 for tracking signals along the trajectory. In the following pages, supporting link analyses for the two LV and one SV tracking stages will be presented.

2. Geometry and coordinate definition for dynamic link analysis

2.1 Antenna coordinate system space vectors of interest

Figure 1 illustrates the antenna coordinate system space vectors of interest [5].

2.2 Antenna coordinate system definition

Figure 2 defines the antenna coordinate system used in this chapter. The azimuth (AZ or Φ) or clock angle is used in the antenna cut configuration. The elevation angle (EL or Θ) also called as cone angle is also used in the antenna gain data file. The antenna gain is a changing variable as a function of mission elapsed time (MET). The antenna gains are used in the following dynamic links.

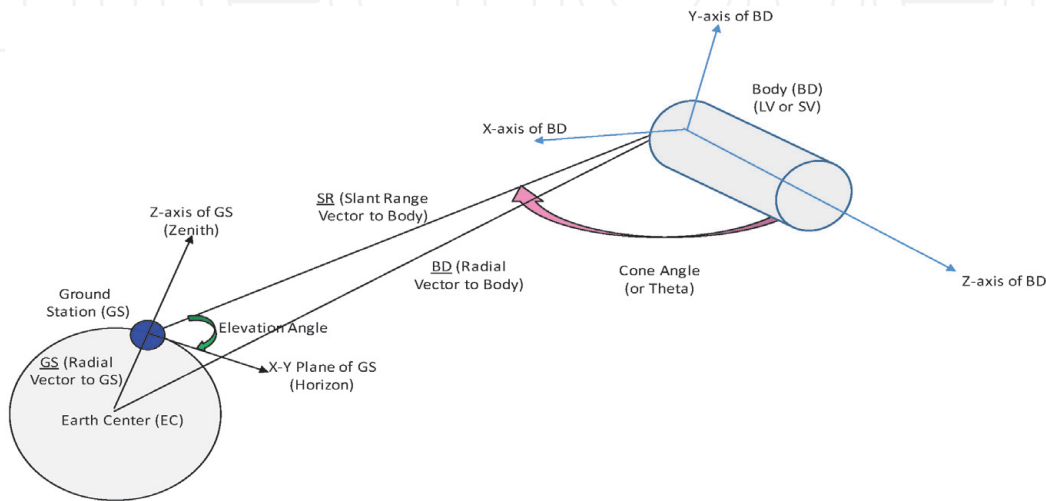


Figure 1.
Space vehicle and ground station vector definition.

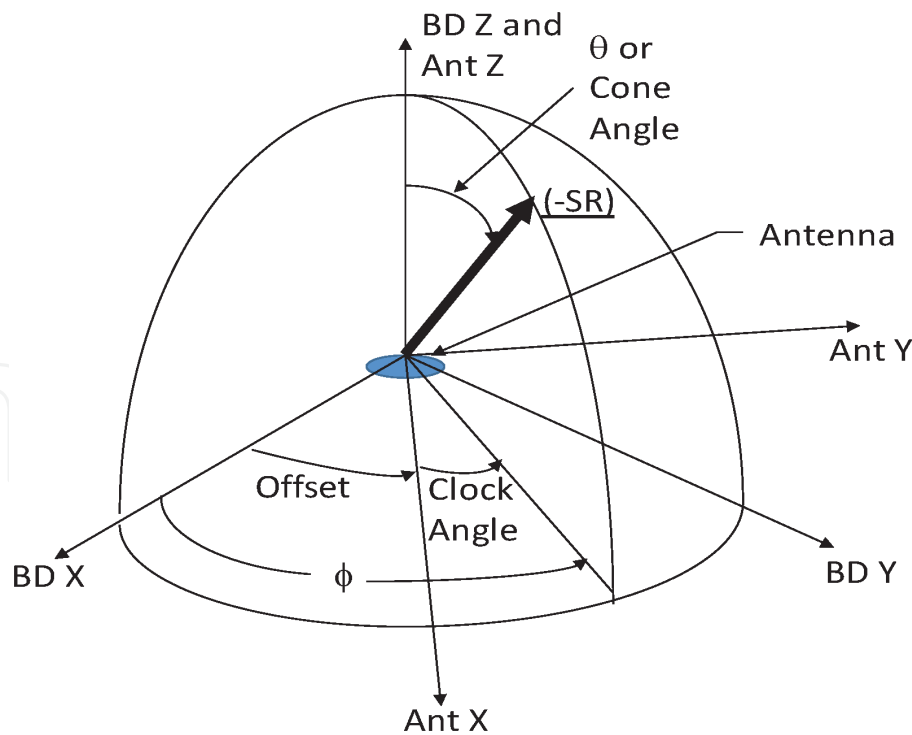


Figure 2.
Antenna coordinate definition.

3. Dynamic link calculation

3.1 Dynamic link formulas of interest

This section provides a summary of the dynamic link model of interest [6]. More detailed derivation of other variables, especially UVZBD, UYVBD, and UVXBD, can be found in [5]. For station elevation angle, either LV or SV elevation or cone angle (EL or theta or Θ), and LV or SV clock or azimuth angle (AZ or Phi or Φ), we have¹

$$\text{Cone Angle} = \frac{180^0}{\pi} \cos^{-1} \left(\frac{\text{UVZBD} \cdot (-\text{SR})}{|\text{SR}|} \right) \text{ in Deg} \quad (1)$$

$$\text{EL} = 90^0 - \frac{180^0}{\pi} \cos^{-1} \left(\frac{\text{GS} \cdot \text{SR}}{|\text{GS}| * |\text{SR}|} \right) \text{ in Deg} \quad (2)$$

$$\varphi = \frac{180^0}{\pi} \tan^{-1} \left(\frac{\text{UVXBD} \cdot (-\text{SR})}{|\text{SR}|}, \frac{\text{UYVBD} \cdot (-\text{SR})}{|\text{SR}|} \right) \text{ in Deg} \quad (3)$$

$$\text{Clock Angle} = \Phi - \text{Offset}$$

3.2 Tracking signals and link analyses along the trajectory

As mentioned in the introduction, there are three separate tracking signals along the flight trajectory that we need to analyze ensuring that they have adequate link margins of three dB or more. Most of the present DLA covers only two stages of launch coverage and neglecting the third stage coverage. The requirement for third stage tracking is explained below:

¹ The authors would like to thank Dr. James Yoh for his derivation of these formulas.

1. From liftoff to the end of LOS, the waveform for this link is generally a digital FM or BPSK for telemetry downlink as defined in the Range Commander Council (RCC) 119-88 [2]. The liftoff to LOS 5 link margin plot is shown in the left half of **Figure 3** for five different ground stations.

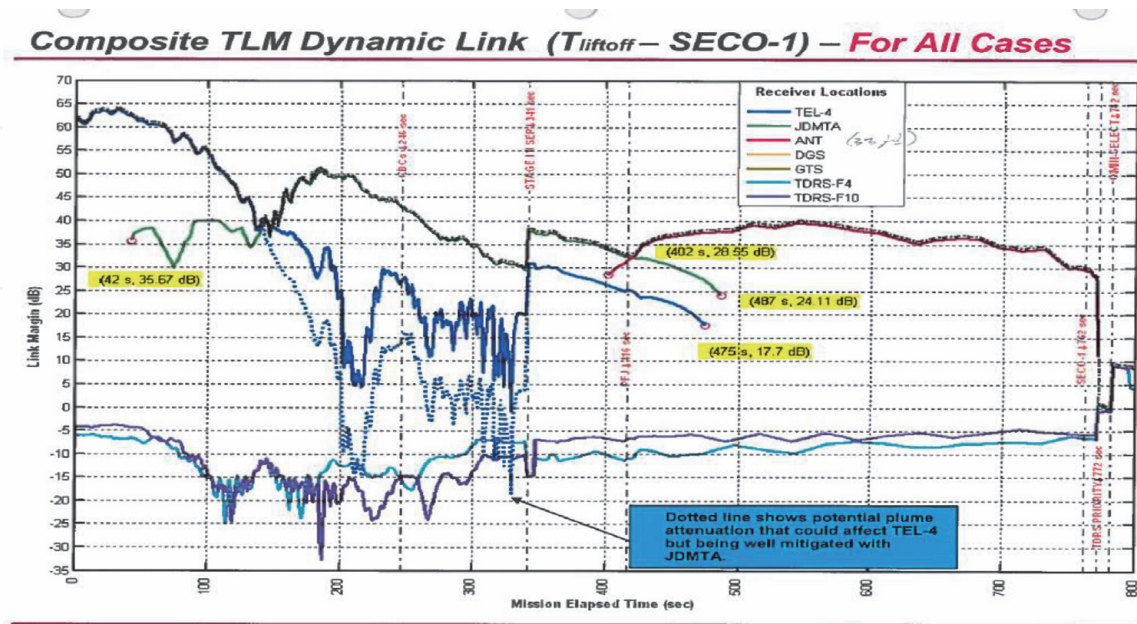


Figure 3.
TLM dynamic link margin from TEL4 to TDRSS versus mission elapsed time.

LV to TDRSS Range TLM Link			
Service:	SA	Mode:	
Frequency: (2200-2300MHz Typ.)	2211 MHz	Polarization:	LHCP
Space-Space Link (EELV)	Value	Range (km):	40347
1 EELV Transmit Power	44.15 dBm	Units	Notes
2 A/B Cable losses	1.5 dB		User Provided Data
3 A/B Antenna Gain	2.1 dBic		User Supplied Data
4 Pointing loss	0.0 dB		User Supplied Data
5 EELV EIRP	44.7 dBm		(1)-(2)+(3)-(4)
6 Space Loss	191.45 dB		LMAC SR= 132 339 260 ft ,near Geo
7 Atmospheric Loss	0.00 dB		Not considered
8 Multipath Loss	0.00 dB		Not considered
9 Polarization Loss	0.10 dB		Not considered
10 Pisotropic at Input to TDRSS	-146.85 dBm		Piso = (5)-(6)-(7)-(8)-(9)
11 TDRS SA Antenna G/T	10.4 dB/K		CLASS Database
12 Self/Mutual Interference (Lim) Loss	0.00 dB		CLASS Database
13 C/No @ TDRSS	62.15 dB-Hz		C/No = Piso+G/T+1/k-Lim
14 Bandwidth BW	54.1 dB-Hz		k = -198.6dBm/K-Hz
15 C/N =SNR @ TDRSS	8.05 dB		256 KBPS BPSK, Detection BW 256KHz
Space-Ground Link (NASA Data)			C/No - BW (13-14)
16 TDRSS EIRP	26.33 dBW		CLASS Database
17 Path Loss	207.32 dB		CLASS Database
18 Atmospheric Loss	0.25 dB		CLASS Database
19 Polarization Loss	0.03 dB		CLASS Database
20 Rain Attenuation	6.00 dB		99.5%WSC, ~97%Guam
21 Pisotropic @ WSC Station	-187.27 dBW		Piso =(16)-(17)-(18)-(19)-(20)
22 Ground G/T	41.00 dB/K		CLASS Database
23 TDRS Dwnlink C/No (Thermal)	82.33 dB-Hz		C/No= Piso @Gnd+Gnd G/T+ 1/k
24 IM/XPOL degradation	3.94 dB		Class analysis (P/IM=20.83dB)
25 TDRSS Dwnlink C/No (Total)	78.39 dB-Hz		C/No-degradation (23)-(24)
26 Bandwidth BW	54.1 dB-Hz		256KBPS BPSK, Detection BW 256KHz
27 TDRSS Dwnlink C/N =SNR (Total)	24.29 dB		C/No - BW (25-26)
Ground Terminal			
28 C/N @ Ground	7.95 dB		(15) // (27)
29 Bandwidth BW	54.1 dB-Hz		256 KBPS BPSK, Detection BW 256KHz
30 MA Net combiner Gain	0.00 dB		MA Ant. Not Used, SA Only
31 C/No @ Ground	62.05 dB-Hz		C/N+BW+Gain
32 Channel power Split	-3.01 dB		Q, Ch
33 Ch C/No @ Ground	59.04 dB-Hz		User Provided Reference Data
34 Bit Rate	54.1 dB		(31)+(32)
35 Eb/No =SNR into Demodulator	4.94 dB		dB-BPS, user provided, 256KBPS
36 Dynamics loss	0.00 dB		(33)-(34)
37 User constraint loss	0.00 dB		Not considered
38 RFI loss	0.1 dB		WCS
39 Implementation loss	1.0 dB		WCS
40 Net Eb/No	3.84 dB		(35)-(37)-(38)-(39)
41 Theoretical Req. Eb/No	4.20 dB		BER=1e-5 with FEC, WCS
42 Margin	-0.36 dB		Margin=Net Eb/No - Req Eb/No
43 Margin (W/o Ch. Pwr Split)	+2.65 dB		(42)-(32) No Pwr Split Loss

Table 1.
LV to TDRSS range TLM link (based on NASA source).

2. From the end of LOS to NASA TDRSS at geosynchronous orbit, the telemetry link is a BPSK or QPSK (telemetry + data) which is sent from LV to TDRSS to be relayed to White Sands or Goddard ground station (WSGT/GRGT), as shown in the second right half of the **Figure 3** and in more link details in **Table 1**.

3. For the third link after SV payload separation, when the satellite or SV starts its transfer orbit, the tracking link from the SV payload (or bus) to an AFSCN ground station will be in SGLS, Unified S-Band (USB), or a NSGLS waveform as described in more detail in [3, 4]. For a more secure tracking, SV normally will be using SGLS link for tracking as described in [4], with a MEO satellite in **Table 2** as an example. A commercial and less secure SV launch may use USB

	Parameter	Unit	Uplink Link (Ground Station to SV)	Downlink Link (SV to Ground Station)
A	B	C	D	F
Transmit System				
5	Carrier frequency (fc)	MHz	1791.700	2237.500
6	Power (Pt)	dBm	57.00	37.00
7	Tx circuit loss	dB	-1.00	-3.00
8	Antenna diameter	m	10.0000	NA
9	Antenna peak gain (Gt)	dB	43.94	2.00
10	EIRP	dBm	99.94	36.00
Transmission Media				
13	Atmospheric loss	dB	-0.10	-0.20
14	Polarization Loss	dB	-1.80	-0.30
15	Total transmit losses	dB	-1.90	-0.50
16	Slant range/Max path	km	24713.00	24713.00
17	Space loss (Ls)	dB	-185.37	-187.30
18	Received isotropic power (RSSi, Piso)	dBm	-87.32	-151.80
Receive System				
21	Antenna diameter	m	0.058	10.060
22	Polarization loss	dB	-0.20	-0.20
23	Antenna gain-peak (Gr)	dB	2.00	45.23
24	Received power @ antenna hub (Pr=C)	dBm	-85.52	-106.77
25	Antenna temperature (TA)	°K	290.00	22.00
26	Receiver line loss (L)	dB	10.00	1.00
27	Receiver noise figure (NF)	dB	2.50	1.10
28	System temperature (Ts)	°K	5157.01	202.32
29	Antenna gain/System temp. (Gr/Ts)	dB/K	-35.12	22.17
30	Noise spectral density @ ant. hub (No)	dBm/Hz	-161.48	-175.54
31	C/No at Receiver Input	dB-Hz	75.95	68.77
Carrier Service				
34	Carrier modulation loss	dB	UL LINK (to SC) -2.25	DL LINK (to Station) -7.45
35	Residual Carrier C/No @ rcvr input	dB-Hz	73.70	61.32
36	Loop Noise bandwidth, B	Hz	20.00	20.00
37	Received C/N	dB	60.69	48.31
38	Required C/N	dB	15.00	17.00
39	Service Margin	dB	45.69	31.31
CMD Service (3-FSK)				
43	Command modulation index	rad	UL LINK (to SC) 0.90	DL LINK (to Station) 1.12
44	Command modulation loss	dB	-5.22	-7.86
45	Rcvd CMD (Pcmd/No) @ rcvr input	dB-Hz	70.73	60.91
46	Data rate (Rb)	bps	1000.00	
48	Received Eb/No	dB	40.73	
49	Required Eb/No	dB	17.60	
50	Service Margin	dB	23.13	
PRN Ranging (coherent only)				
53	Ranging modulation index	rad	UL LINK (to SC) 0.30	DL LINK (to Station) 0.37
54	Ranging modulation loss	dB	-12.45	-18.84
55	Rcvd Ranging (Prn/No) @ rcvr input	dB-Hz	63.51	49.94
56	Data Rate, Noise Bandwidth, B	Hz	NA	10.00
58	Received C/N	dB	NA	39.94
59	Required C/N	dB	NA	28.00
60	Service Margin	dB	NA	11.94
Telemetry Service (BPSK on 1.024 MHz S/C)				
64	TLM modulation index	rad	UL LINK (to SV) N/A	DL LINK (to Station) 1.30
65	TLM modulation loss	dB	N/A	-5.94
66	Rcvd TLM (PtIn/No) @ rcvr input	dB-Hz	N/A	62.83
67	Data rate (Rb)	kbps	N/A	1.00
69	FEC Coding Gain	dB	N/A	0.00
70	Received Eb/No	dB	NA	32.83
71	Required Eb/No	dB	N/A	9.60
72	Service Margin	dB	N/A	21.23

Table 2.
Link budgets for SGLS TT&C uplink and downlink services [4].

	Parameter	Unit	Uplink Link (Ground Station to SV)	Downlink Link (SV to Ground Station)
A	B	C	D	F
Transmit System				
5	Carrier frequency (fc)	MHz	1791.700	2237.500
6	Power (Pt)	dBm	57.00	37.00
7	Tx circuit loss	dB	-1.00	-3.00
8	Antenna diameter	m	10.0000	NA
9	Antenna peak gain (Gt)	dBi	43.94	2.00
10	EIRP	dBm	99.94	36.00
Transmission Media				
13	Atmospheric loss	dB	-0.10	-0.20
14	Polarization Loss	dB	-1.80	-0.30
15	Total transmit losses	dB	-1.90	-0.50
16	Slant range/Max path	km	24713.00	24713.00
17	Space loss (Ls)	dB	-185.37	-187.30
18	Received isotropic power (RSSi, Piso)	dBm	-87.32	-151.80
Receive System				
21	Antenna diameter	m	0.058	10.060
22	Polarization loss	dB	-0.20	-0.20
23	Antenna gain-peak (Gr)	dBi	2.00	45.23
24	Received power @ antenna hub (Pr=C)	dBm	-85.52	-106.77
25	Antenna temperature (TA)	°K	290.00	22.00
26	Receiver line loss (L)	dB	10.00	1.00
27	Receiver noise figure (NF)	dB	2.50	1.10
28	System temperature (Ts)	°K	5157.01	202.32
29	Antenna gain/System temp. (Gr/Ts)	dB/K	-35.12	22.17
30	Noise spectral density @ ant. hub (No)	dBm/Hz	-161.48	-175.54
31	C/No at Receiver Input	dB-Hz	75.95	68.77

Table 3.
Typical C/No for uplink and downlink budgets.

or NSGLS for SV tracking instead of using SGLS waveform. **Table 3** shows link budget for uplink and downlink C/No example for tracking links 1 and 2. **Table 2** shows SGLS telemetry, tracking, and command (TT&C) link budget for tracking link 3 for a MEO satellite. If the SV is using a USB or a NSGLS [3], the tracking waveform can be an AQPSK signal with telemetry on the I channel and ranging on the Q channel.

4. Basic link parameters and formulas

This section describes the basic link parameters including LV or SV transmitter power amplifier gain (Pt), transmitter antenna gain (Gt), space loss (Ls), received isotropic power (RIP), and received (C/No = SNR).

A modulation signal or information data is generated at a ground station, in an LV or in an SV. This modulation signal will be used to modulate onto the radio frequency (RF) carrier to become a modulated transmit signal. This transmit system will be consisting of a high-power amplifier (HPA) which amplifies the signal to generate an output power expressed in dBW (conversion from Watts to dBW is simply $dBW = 10 \cdot \log_{10}(Watts)$); some cables and circuits with a loss and an antenna with a gain are added together as shown below. The output from the transmit system is therefore an effective isotropic radiated power or EIRP, which can be found in either the uplink or the downlink of an LV or an SV tracking system.

$$EIRP = P_T + L_C + G_t \text{ in dBW} \tag{4}$$

where G_t = transmit antenna gain, in dBi; L_C = transmit circuit loss, in negative dB; and P_T = HPA output power, in dBW.

For the uplink, where the transmit antenna is located on the ground, the antenna can be easily directed to an LV or SV. This transmit antenna is likely to be a directional high gain dish antenna for connectivity with an LV or SV located possibly far away. In **Table 3**, line 9, a typical ground station has a large parabolic antenna dish with a gain $G_t = 43.94$ dBi using the following formula.

$$G_t = 10 * \log 10 \left[\eta * \left(\frac{\pi * f_C * D}{c} \right)^2 \right] \text{ in dBi} \quad (5)$$

where η = average antenna efficiency (0.70 in the calculation in **Table 3**); f_C = uplink frequency, in Hz; D = antenna diameter, in m; and c = speed of light, in m/s.

For the downlink, the transmit antenna is typically an omnidirectional antenna that covers a larger portion of the sky or the Earth, in which case the antenna gain is small (e.g., 2 dBi) and is either specified as in line 9 of **Table 3** or can be interpolated from values extracted from a table of antenna gain pattern with a specific AZ, EL, and MET, using a mission specific launch trajectory.

In general, there are terms that may be added to **Tables 2** and **3**. For example, the uplink transmit antenna in **Table 3** may have two more loss terms, namely, radome loss to account for any loss for a radome and pointing loss to account for any pointing error in directing the boresight of the antenna. For **Table 3** they are both negligible and ignored except for the polarization losses. The transmit and receive polarization losses (lines 14 and 22, respectively, in **Table 3**) can be accounted for as one-single combined receive polarization loss.

4.1 Transmission medium and losses

The signal path traverses through the transmission medium, in between transmit and receive systems. When the distance between transmit and receive systems increases, the signal beam has an angular spread which decreases the signal power collected by a receiving antenna. We know that the portion of the transmission medium near the ground station depends on the Earth's atmosphere which attenuates the signal to different degrees, depends on the frequency, the altitude of the GS, and the angle of the signal path through the atmospheric (GS elevation angle). Beyond the Earth's atmosphere, the signal path traverses through the space with little atmospheric attenuation, only with free space loss to account for. Therefore, there are essentially two losses through the transmission medium, namely, the space loss to account for the spreading of the signal beam and the additional atmospheric loss [8].

$$L_S = 10 * \log 10 \left[\left(\frac{c}{4\pi * f_C * SR} \right)^2 \right] \text{ in dB} \quad (6)$$

where f_C = carrier frequency, in Hz; c = velocity of light, in m/s; and SR = slant range between GS and SV, in m.

At L and S bands, the atmospheric loss is very small, at less than 0.001 dB/Km or 0.1 dB/100Km for a link availability of better than 98% [8].

4.2 Received isotropic power

The transmit signal, after accounting for the space and atmospheric losses, and its signal path terminates at the antenna of either the ground station, the SV, or the LV receiving system. Before considering the characteristics of the receive antenna

and the receiver, a good indication of the signal strength is given by the received isotropic power. RIP is simply the transmitter EIRP after subtracting off the losses of the transmission medium, i.e.

$$\text{RIP} = \text{EIRP} + L_S + L_A \text{ in dBW} \quad (7)$$

where L_A is the atmospheric loss extracted from tables or curves, in negative dB (very small at 0.02 dB/Km per Datron chart in L and S bands). L_S can also be obtained from the Datron calculator [8].

4.3 Receive system and performance

The last portion of **Table 3** addresses the receiving system and assesses how well it performs. This section involves with the calculation of the signal strength and the noise strength, resulting in the ratio of signal power over noise power density (C/N_0). In general, we first address the signal power and then the noise power density. Line 21 provides for the receive antenna size consistent with the receive antenna gain to be calculated later. The next parameter in **Table 3** is the polarization loss, which accounts for the mismatching between the polarization axial ratios of the received signal and the receiving system. The axial ratio is the ratio of the major axis of an ellipse to its minor axis. For circularly polarized signal, the ratio should be 0 dB. Any deviation from 0 dB results in a polarization loss. Line 23 shows the values of receive antenna gain. For downlink in which the receive antenna is a dish antenna located at GS, G_r is calculated using the standard dish antenna equation (similar to Eq. (6) for G_t).

$$G_r = 10 * \log 10 \left[\eta * \left(\frac{\pi * f_C * D}{c} \right)^2 \right] \text{ in dBi} \quad (8)$$

where η = average antenna efficiency (assumed to be 0.6 in the calculation in **Table 3**); f_C = downlink frequency, in Hz; D = antenna diameter, in m; and c = velocity of light, in m/s.

At the end, the received power at the antenna feed is just the sum of RIP, minus the polarization loss, plus the receive antenna gain, i.e.

$$C = \text{RIP} + L_P + G_r \text{ in dBW} \quad (9)$$

where L_P is the polarization loss, in negative dB.

For the downlink transmit antenna on the SV, as in the case of uplink receive antenna, the SV antenna is a broad beam Earth coverage (EC) omnidirectional type of SV antenna, with a gain of 2 dBi (see line 23 of **Table 3**).

For the noise power density (N_0), we need to calculate the system temperature (T_S) measured at the antenna feed. The system temperature is the sum of antenna sky temperature (T_A) and the composite temperature from antenna line loss (L_L) and low noise amplifier noise figure (NF) which are referred to the antenna feed. In linear quantity, T_S is given by [1].

$$T_S = T_A + \left(10^{(L_L + \text{NF})/10} - 1 \right) * 290 \text{ in Deg} - \text{K} \quad (10)$$

where NF = low noise amplifier noise factor, in dB and L_L = line loss, in dB. The noise density (N_0) is given by

$$N_0 = k\bar{dB} + 10 * \log(T_s) \text{ in dBW/Hz} \quad (11)$$

where k = Boltzmann's constant in dB = -228.6 dBW/KHz.

Using Eqs. (9) and (11), the ratio C/N_0 at the receiver input is obtained in **Table 3**, line 31. It represents the final product before going into specific service(s) such as telemetry and ranging to evaluate their performance.

5. Space vehicle link services

For many SVs, we are interested in their uplink and downlink services. **Table 2** shows an example, taken from an IEEE paper [4]. This is the standard link budget, where the ground station is an AFSCN [3] remote tracking station (RTS) using SGLS waveform [3, 4]. The waveform is described in an AFSCN interface control document (ICD) [3] and is implemented in DLA, although other waveforms can be readily incorporated. The uplink has two services of interest—carrier and command—while the downlink has three services of interest: carrier, ranging, and telemetry. In general service margins are calculated for these five services. For the SGLS waveform, command is coupled with ranging and modulated on the uplink carrier; therefore command is also turned around at the SV along with ranging. This SGLS turnaround process explains the reason that **Table 2** shows a power allocation for command in the downlink and no calculation for its margin. As a result, downlink power allocated to command is essentially wasted while robbing power from other downlink services. The requirements and service margins for command and telemetry are expressed in E_b/N_0 , since it is the bit error rate (BER) that counts for both cases. The carrier and ranging are expressed in C/N_0 given by a specific station. For ranging, it is the autocorrelation value between the decoded ranging code and the transmitted ranging code that needs to be maximized in order to successfully perform accurate ranging.

Table 2 represents uplink and downlink budgets for SGLS TT&C. Let us address the important aspects of the calculation of uplink and downlink services in the next few subsections. The role of modulation indices is to divide up the power for allocation to services. The modulation index is expressed in radians so that it can go right in as an argument in a sinusoidal or Bessel expression. If the modulation indices of all services are zero radians, no power is allocated to the services, and the carrier retains all the link power calculated in Section 4. If the modulation indices of services are not zero, portions of the power are taken from the carrier and allocated to the services. The remaining power stays with the carrier as the “residual carrier power.”

5.1 SNR and link margin calculation

After SV separation, we are dealing with the SV uplink and downlink using SGLS or NASA Unified S-Band waveforms as described in [3, 4]. For telemetry service, the requirement is $SNR = P_{\text{service}}/N_{\text{0B}} = E_b R_b/N_{\text{0B}} = E_b/N_0$ in dB. For carrier and ranging, the requirements are stated in terms of C/N_0 as mentioned before. For acquisition, the uplink carrier loop bandwidth could be as high as ± 100 KHz, while its tracking bandwidth could be as small as a few Hz. For the station the carrier tracking loop bandwidth is about 20–50 Hz, as in **Table 2** in line 36. For ranging, the bandwidth of 10 Hz represents ranging tracking loop bandwidth (**Table 2**, line 56), which corresponds to the sampling rate of the autocorrelation

Uplink service modulation losses for SGLS and NASA USB				
No.	Uplink modulation	Carrier	Ranging	Command
1	AM-3FSK/PRN RNG/PM (SGLS unfiltered uplink) [3, 4]	$J_o^2(\beta_1).cos^2(\beta_2)$	$J_o^2(\beta_1).sin^2(\beta_2)$	$2J_1^2(\beta_1).cos^2(\beta_2)$
2	BPSK/PRN RNG/PM (USB filtered case) (Eqs. (1-22) and (1-23)) [9]	$J_o^2(\beta_1)cos^2(\beta_2)$	$J_o^2(\beta_1) sin^2(\beta_2)$	$2J_1^2(\beta_1) cos^2(\beta_2)$
3	BPSK/Tone RNG/PM (USB unfiltered case) (Eqs. (1-18) and (1-21)) [9]	$J_o^2(\beta_1) J_o^2(\beta_2)$	$2J_o^2(\beta_1)J_1^2(\beta_2)$ +	$2J_o^2(\beta_2) J_1^2(\beta_1)$ +
Downlink modulation losses for SGLS and NASA USB				
No.	Downlink modulation	Carrier	Ranging	Telemetry
4	PRN RNG/PSK TLM/PM (SGLS filtered case) (Eqs. (2-18) and (2-20)) [4]	$J_o^2(\beta'_1)J_o^2(\beta'_2)$ $J_o^2(\beta_3)$	$2J_o^2(\beta'_1) J_1^2(\beta'_2)$ $J_o^2(\beta_3)$	$2J_o^2(\beta'_1)J_o^2(\beta'_2)$ $J_1^2(\beta_3)$
5	Tone RNG/PSK TLM/PM (USB filtered case) (Eqs. (2-18) and (2-21)) [9]	$J_o^2(\beta_3)J_o^2(\beta'_2)$	$2J_o^2(\beta_3)J_1^2(\beta'_2)$	$2J_o^2(\beta'_2)J_1^2(\beta_3)$

Table 4.
Uplink and downlink service modulation losses for SGLS and NASA USB.

value between the detected ranging code and the transmitted ranging code. For command and telemetry, the requirements are expressed in terms of E_b/N_0 . The command and telemetry data bit rates of 1000 bps each are representing the lower end of their SGLS choices. As shown in **Table 2**, the results from the SNR calculation are the values of C/N and E_b/N_0 for various received uplink services (lines 37 and 48 for command C/N or E_b/N_0) and for various downlink services (line 55 for ranging service $Prng/No$ and line 70 for telemetry service Eb/No). The uplink service modulation losses for SGLS and NASA USB with subcarrier (S/C) [3, 4, 9] are shown in **Table 4**. The downlink service modulation losses for SGLS and NASA USB with subcarrier (S/C) [3, 4, 9] are shown in **Table 4**. Also note that β_1 , β_2 , and β_3 represent the modulation indices for command (CMD), ranging (RNG), and telemetry (TLM), respectively, per [3, 4, 9]. These uplink and downlink modulation losses are in lines 34, 44, and 54 in **Table 2**.

For NSGLS waveforms such as the direct mod BPSK, QPSK, and AQPSK, the service mod losses are negligible. Finally, the calculated service SNR in **Table 2** is compared with the required SNR to obtain the link margin for each service. The required SNR values capture all the performance requirements for the services, such as ranging accuracy, tracking loop loss likelihood, bit error rate, and others.

6. Launch vehicle dynamic link

Before SV separation from the LV, we are also interested in the dynamic link from a ground station to the LV, from liftoff to the SV after separation, along the entire LV flight path using the tracking stations in the line of sight (TEL4, JDMTA, ANT, DGS, TDRSS). The waveforms for this LV tracking are described in Range Commander Council (RCC) handbook [2]. One must ensure that the downlink telemetry link from the launch vehicle to these ground stations and TDRSS relay satellite are positive as can be seen in **Figure 3**. The basic LV range modulations are digital FM, BPSK, QPSK, AQPSK, etc. as discussed in RCC [2]. In **Figure 4**, dynamic LV slant range “received TLM Eb/No ” and “TLM link margin” for a specific mission

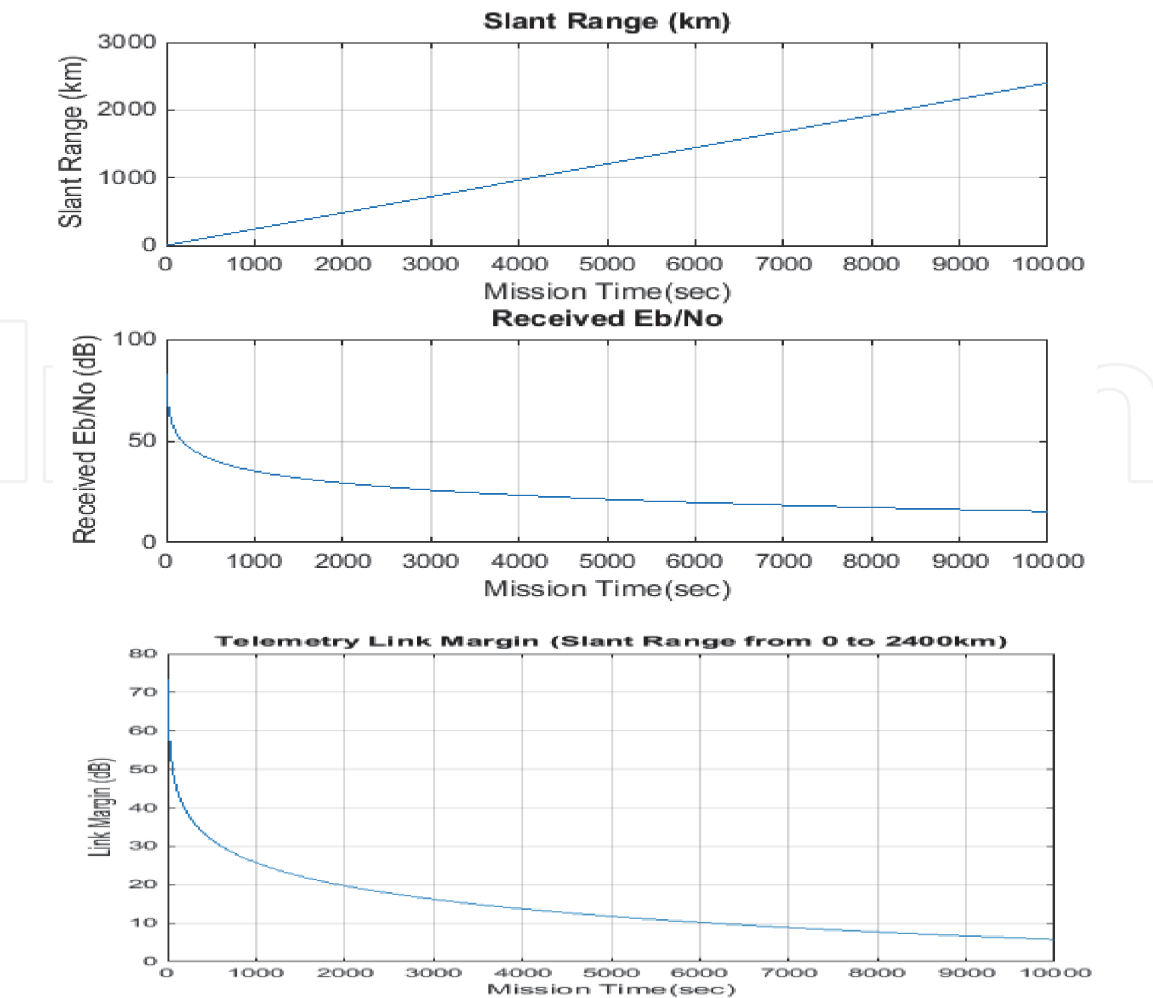


Figure 4.
LV slant range received TLM Eb/No and TLM link margin.

are displayed together. As an example a specific LV to TDRSS BPSK link using NASA data is shown in **Table 1**.

7. Conclusion

This chapter discusses the required three DLAs and related tracking waveforms to cover the three launch stages, namely, (a) the launch vehicle tracking link from liftoff to its end LOS using the digital FM or BPSK signal, (b) the launch vehicle tracking link from LOS to TDRSS at BLOS using NASA USB signal, and (c) the final tracking link from SV to an AFSCN ground station using AFSCN SGLS, AFSCN NSGLS, or NASA USB waveforms. In the third tracking link case, BPSK, QPSK, or AQPSK waveforms were used, in which for QPSK and AQPSK, the telemetry data is put on the I channel and the ranging signal is on the Q channel.

The chapter shows that good telemetry link margins from LV to tracking stations such as TEL4, JDMTA, and ANT or to a NASA TDRSS relay satellite can be achieved using digital FM, BPSK, QPSK, or AQPSK signals, after SV separation. The chapter also shows that good tracking link margins can be achieved from SV to AFSCN ground stations, including IOS or DGS as the first contact station.

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